SIMULTANEOUS MEASUREMENTS OF INDOOR AND OUTDOOR AIR QUALITY, ITS CHEMICAL COMPOSITION AND RELATIONSHIP WITH METEOROLOGY AT AGRA

Synopsis

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INTRODUCTION

From smog hanging over cities to smoke inside our homes, air pollution poses one of the biggest environmental threats to human health and climate change. Millions of people die, prematurely, from diseases caused by air pollution. Every year, exposure to air pollution is estimated to cause 7 million premature deaths and result in the loss of millions of healthy years of life (WHO, 2021). It also contributes to less-liveable conditions in cities and hinders economic competitiveness. Improving air quality can enhance climate change mitigation efforts, while reducing emissions will in turn improve air quality (WHO, 2021). These findings highlight that air pollution is now one of the world's largest environmental health risk and millions of premature deaths may be avoided by reducing air pollution, in outdoors and indoor environments (Jorquera *et al.,* 2019).

Urbanization and industrialization for the better quality of life has polluted the air we breathe. Although outdoor air quality guidelines have been constantly implemented during the last decades and its pollutants are well documented, but there is lack of information on similar trends for indoor air. As most of the people spend more than 90% of their time indoors, measures to improve the quality of air must be adopted (Abbatt *et al.,* 2020). Thus, Indoor Air Quality (IAQ) has become an essential area of research in the twenty-first century and an environmental and public health concern over the past few decades. People have developed awareness about the quality of air they breathe and on the impact of indoor environment on our health and well-being. In developing countries, air quality in indoor environment has been less extensively studied than outdoor air. Outdoor sources considerably affect indoor particulate matter (PM) concentrations particularly when infiltration rates of outdoor particles are high (Abdel-Salam *et al.,* 2021). Outdoor and indoor air has varied composition. Many studies confirm that indoor air is more deadly than outdoor air (Saini *et al.,* 2020). No national or international regulations have been prescribed for indoor air quality nor there are any standardize procedures available for indoor pollution measurements (Tofful *et al.,* 2020). Several studies have reported higher levels of airborne pollutants in indoor environments in comparison to outdoors (Gonzalez-Martins *et al.,* 2021). The concern to care for better indoor environment has intensified during the COVID-19 pandemic as there are greater quarantine implications and lockdowns (Mann *et al.,* 2021).

Indoor air is a mixture of particles that mainly originate from indoor sources, are infiltrated from outdoors, or formed indoors through chemical reactions of gas-phase precursors. Thus, the concentration and chemical composition of indoor air depends not only on its indoor emission rate, but also on the rate at which it is being transported from outdoors to indoors, and the rates at which it is scavenged by indoor surfaces, consumed by indoor chemistry, and removed by ventilation or filtration (Weschler, 2009). In the absence of indoor aerosol sources, indoor concentrations are known to be correlated to the concentrations outdoors through the migration of outdoor aerosol indoors (Talbot *et al.*, 2017). Therefore, understanding the composition and sources of indoor pollution and its relation to outdoor sources are essential for the assessment of personal exposure (Tofful *et al.,* 2021). Although these pollutants are often present in low concentrations in buildings, long-term exposure can cause significant risks to human health (Tran *et al.,* 2020). Quantifying this component of exposure by separating PM of indoor and outdoor origin may throw more light on the impact of outdoor environment over indoor environment.

The quality of the indoor environment is of major concern since the indoor air is typically polluted by outdoor air enriched with additional pollutants that are emitted by building materials, consumer products and other human activities. Therefore, the indoor air can be significantly more polluted than outdoor, with most pollutants exhibiting indoor-to-outdoor ratios larger than unity. In addition, personal exposure may also be from the sources such as cooking, cigarette smoking, degradation of VOCs from heating systems, re-suspension of house settled dust and cleaning activities are usually responsible for emission of harmful pollutants indoors (Spiru *et al.,* 2017; Salthammer *et al.,* 2018). Contrarily, sources like vehicular exhaust, industrial emissions, and residential heating tend to enhance the pollution outdoors. The relation between outdoor measurements and indoor exposure may be established by the study of infiltration of these particles into buildings coupled with their fate in the indoor air. In both environments, PM is a widespread complex mixture of solid and liquid particles suspended in air with varied size, shape, origin, and composition (Zhang *et al.*, 2021). It is also known as human carcinogen and its chemical composition comprises of inorganic ions (sulfates, nitrates, ammonium, and water-soluble metals), heavy metals, elemental carbon, organic compounds including VOCs (volatile organic

ompounds), PAHs (polyaromatic hydrocarbons) and polychlorinated biphenyls, biological components (allergens), microbial agents, and water (Oliveira *et al.,* 2019).

PM has been associated with premature death and asthmatic symptoms (Kim *et al.,* 2017; Xu *et al.,* 2017). It may also explain the epidemiology of pollutants and human health. The determination of outdoor to indoor PM contribution is especially important when measuring PM concentrations in occupied residences. Many human activities generate or resuspend significant amounts of PM, potentially obscuring the impact of outdoor PM. This indoor-generated PM is correlated to human activities and indoor processes but may not be correlated to outdoor concentrations (Śmiełowska *et al.,* 2017).

Outdoor PM is well dispersed in the atmosphere (from natural and anthropogenic sources), from which a substantial proportion of outdoor PM may be transported indoors. It is composed of a complex variety of constituents including dusts, aerosols, smoke, fumes and liquid droplets, while their dispersion is influenced by meteorological factors such as wind speed, wind direction, temperature and relative humidity (Ścibor *et al.,* 2019). Outdoor particles have been shown to contribute to indoor concentrations through building ventilation and openings/cracks within the building shell. Indoor PM concentration is diverse; and depends on emissions and individual sources (Avery *et al.,* 2019). Recently, much consideration has been given to examining and characterising indoor PM in different types of indoor microenvironments (Habilmicr *et al.,* 2021). Indoor combustion is believed to be one of the main contributors of indoor PM elevation. Generally, anthropogenic sources dominate, with a greater quantity of particles in urban areas. Secondary aerosol particles are not directly emitted; but formed by reactions between atmospheric compounds, this yields involatile products. Pollutants of outdoor origin, including those present in the outdoor air and those released from soil sources, can be transported indoors via building openings and cracks (Mitchell *et al.,* 2007).

Inorganic constituents are water-soluble ions and secondary aerosol particles formed from NH_4^+, NO_3^-, and SO_4^{2-}. The gas-to-particle transformation involves three major components in ambient or indoor air: sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and ammonia (NH_3) (Agbo *et al.,* 2021). Similarly, organic constituents also have a major contribution. Indoor air constitutes volatile pollutants such as formaldehyde, acetaldehyde, propanal, pentanal, hexanal, octanal, and nonanal. Among the Volatile

Organic Compounds (VOCs) found in indoor air, these aldehydes are the most frequent and at high concentrations. The main indoor sources of aldehydes are building materials, paints and furniture, as reported in papers dealing with emissions of aldehydes in air by materials. Aldehydes are released into the atmosphere by vehicle exhaust and incomplete combustion of hydrocarbons (Ghislain *et al.*, 2019).

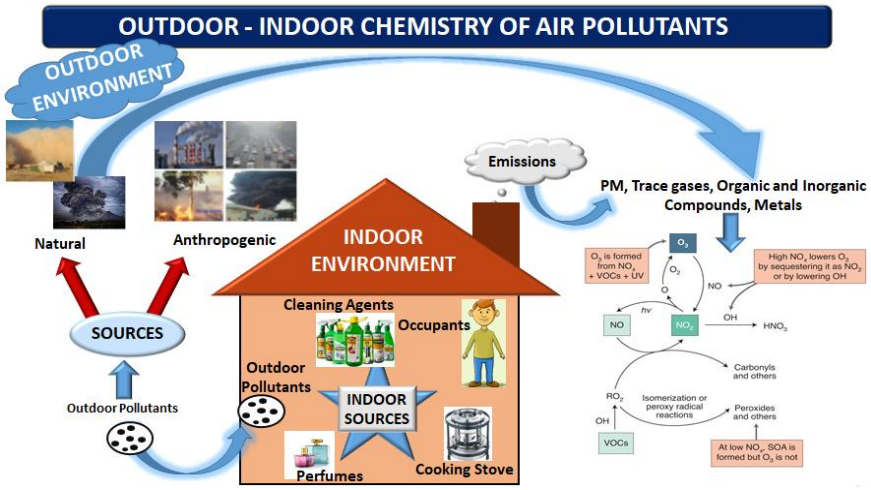

Figure 1: Indoor and Outdoor Constituents of Environment

Formaldehyde, another important component of aerosol, is of concern both indoors and outdoors. Besides formaldehyde, carboxylic acids (propanoic acid and hexanoic acid) can be produced in indoor air by reactions involving ozone and are also highly studied in outdoor air. Carboxylic compounds are significant constituents of atmospheric carbonaceous PM formed from primary emissions and secondary atmospheric reactions. The observed carboxylic and carbonyl compounds in PM include linear monocarboxylic, dicarboxylic and aromatic polycarboxylic acids, hydroxyacids, oxoacids, aldehydes, dialdehydes, ketones and multifunctional aliphatic and aromatic compounds (Rousová *et al.*, 2018). Indoor measurements of carboxylic acids, however, are scanty (Liu *et al.*, 2017). A myriad of VOCs, including alkanes, aromatics, terpenes, alcohols, aldehydes, ketones, esters, and halogenated compounds, have been identified indoors, typically with elevated concentrations compared to outdoors. The main source of VOCs is combustion process and emissions from indoor materials (building materials and consumer products, off-gassing emissions) (Matawle *et al.*, 2017). It is expected that enhancement in indoor sources may lead to rise in concentration of these species. Their outdoor concentration constitutes a considerable source for indoor air via the ventilation process, with a number of studies evaluating the correlation between indoor and outdoor air pollution. Up to 60% of non-

methane VOCs in the urban areas worldwide are constituted by BTEX compounds. Hence, these mono aromatic hydrocarbons are an indicator of the organic pollutants (Ghaffari *et al.,* 2021).

Thus, it is important to characterise IAQ and understand which pollution sources, housing characteristics, and occupancy patterns have the largest impact on our exposure to pollutants present in the indoor environment (Ault *et al.,* 2020). Although there is increasing research being carried out on indoor air quality, there is still significant unknown chemistry which needs to be explored. Thus, further investigation in this area may shed valuable light on the role and contribution of airborne dust as a potentially significant source of air pollution (Saraga *et al.,* 2017). Substantial research until recently has focussed on species that are emitted indoors and relatively little attention has been paid to the significance of the reactions between them (Carslaw *et al.,* 2007). The chemistry taking place in buildings is complex, extensive, and under-studied. Many thousands of species can participate in the chemical transformations in indoor air as precursors, intermediates, or products. These reactive forms may constitute indoor aerosols or alter its composition, while countless different kinds of indoor materials and occupants act as sinks, sources and provide surfaces for chemical transformations. There is lack of scientific understanding related to complex heterogeneous and multiphase chemical reactions, and factors which do not affect outdoor environments (building materials, furnishings, ventilation, indoor lights, etc.) but play a key role in indoor air chemistry. Numerous aspects of indoor environments under investigation make the chemistry unique and need to be accounted for when establishing a framework for understanding the processes occurring indoors (Weschler, 2009). Few studies that characterized the chemical properties in PM are mostly concerned with specific group of hazardous components (Tofful *et al.,* 2020). Moreover, local source pollutants from the ambient environment, including traffic, may potentially cause increments in indoor pollutant concentration via infiltration/penetration through windows, doors, or ventilation systems. Therefore, determining the effects of indoor air pollution on human health has again become an important issue for researchers (Ipek *et al.*, 2021).

The classrooms, where children spend a significant portion of their day, has been identified as one of the most important microenvironments, where PM levels may vary substantially from outdoors due to building insulation and other indoor sources (Ite *et al.,* 2019). Ca-rich particles, motor vehicles,

secondary aerosol formation, soil dust, biomass burning and marine aerosols have been identified as sources affecting $PM_{2\cdot5}$ in school classrooms (Carrion-Matta *et al.*, 2019). Studies report that most of the $PM_{2\cdot5}$ measured in classrooms was generated indoors from continuous re-suspension of soil particles and a mixed source comprising of organic (skin flakes, clothes fibers, possible condensation of VOCs) and Ca-rich particles (from chalk and building deterioration) (Amato *et al.*, 2014).

The indoor environment is very much dependent on the outdoor environment with a more effective penetration of fine particles than coarse particles from outdoors into the house, when there is no indoor source (Liao *et al.*, 2004). In these cases, the ratio of indoor to outdoor PM levels is reported to range from 0.5 and 0.7 where differences between outdoor and indoor air quality are attributed to rates of deposition and infiltration. These studies generally rely on indoor-outdoor air-exchange mass balance models (IO models) and measurements (Hassanvand *et al.*, 2014). This makes it important to understand the characteristics of each air pollutant inside/outside (I/O) the building and the variables affecting the degree of exposure to them (Wei *et al.*, 2019). It is expected that in the absence of internal sources, the ratios I/O (indoor/outdoor) between the concentrations are less than or equal to 1 and the ratios will be higher unit in the presence of significant indoor sources (Pallarés *et al.*, 2019).

Recent studies recognize the necessity of estimating the effect of outdoor PM on indoor concentrations and separating that effect from indoor-generated PM. Accumulation mode indoor/outdoor (I/O) ratios were substantially lower in winter than in summer. This reduction was attributed to particles of outdoor origin shrinking as they entered the warmer and drier indoor environment. An essential factor in this process appears to be the difference (gradient) between the temperature and relative humidity of the indoor and outdoor environments during the winter (Talbot *et al.*, 2017). Although studies have been conducted separately to characterize indoor/outdoor chemistry, there is dearth of studies which simultaneously characterize the chemical composition of indoor and outdoor PM.

Thus, it is crucial to simultaneously characterise ambient air as well as indoor air, so that we can understand its composition and, in the presence of concentrations of chemical species that are dangerous for human health, identifying possible causes for these concentrations (direct or indirect sources of pollutants) (Silva *et al.*, 2017). Moreover, the simultaneous and prolonged monitoring of the indoor as well as outdoor environments where people spend most of their time can provide detailed information

on personal exposure levels to PM and, consequently, on the potential health outcomes affecting the exposed population. It is also important to characterize the physical processes driving particle concentrations as well as chemical composition of indoor air, including inorganic and organic constituents to investigate chemical transformations of these pollutants. Understanding their sources, sinks and transformations is critical to mitigate their health impacts. In this context, the main goal of this work is to develop the scientific knowledge on the origin and the behaviour of indoor pollutants, with an emphasis on particulate matter, and its chemical composition, both indoors and outdoors, simultaneously to obtain a holistic view.

LITERATURE REVIEW

Air Pollution that originates indoors as well as outdoors contributes significantly to human exposure and is a cause of concern to citizens living in urban as well as in rural India. Today, our lifestyle demands a considerable amount of time to be spent within the indoor environment making quantification, variability and health impact assessment of indoor pollutants a necessity (Garg *et al.,* 2021). Therefore, the exposure to hazardous pollutants indoors, rather than outdoors, can have a great impact on human health (Ohura *et al.,* 2009). The concentration of particulate matter varies significantly due to sampling artefact, emission sources and their impact around the study site. The comparison is essential to obtain an overview of pollution levels in different parts of the world. Thus, the levels of PM, inorganic, organic and some metallic composition of PM for the simultaneous study of indoor and outdoor environment are shown in Table 1 (International) and Table 2 (National). A similar table for the outdoor and indoor studies is reported in Tables 3 and 4 respectively to highlight the difference in the concentration of above mentioned pollutants indoors and outdoors.

Table 1: Concentration and composition of PM, trace gases and metals studied simultaneously indoors and outdoors across the globe.

S. No.	EXPOSURE DETAILS					RESULTS			REFERENCE
	I/O pollutant details	**Site descriptions**	**Period of study**	**Samplers used**	**Seasonal comparison**	**Average Indoor (I) and outdoor (O) concentrations (μg/m^3)**	**I/O Output**	**Seasonal Output**	
1.	PM_{10} and $PM_{2·5}$	Residential homes (I): Living room and kitchen; (O): Balcony of living rooms **(Alexandria, Egypt)**	October 2018 to December 2018	Personal Environmental Monitor [PEM-model 200] for PM_{10} and MSP Co., Minneapolis, MN, USA) for $PM_{2·5}$ respectively	-	**PM_{10}** **(I):** Living room: 65·5; **(O)**: 102·9 **$PM_{2·5}$** **(I):** Living room: 34·5; **(I)** Kitchen: 70·4; **(O)**: 48·3	The mean I/O ratios of $PM_{2·5}$ were found to be higher than that of the PM_{10}	-	Abdel Salam, 2021
2.	PM_{10} and $PM_{2·5}$ with their chemical constituents	Residential homes (I): Living room and bedroom; (O): Balcony **(Rome, Italy)**	25th February 2013 to 14th March 2013	Silent Sampler, FAI Instruments, Fonte Nuova – Rome, Italy	-	$PM_{2·5}$ (O): 44 ± 14, 26 ± 9 and (I): 39 ± 11, 17 ± 4 during the first and second sampling periods respectively. PM_{10}: 36 ± 14 and 16 ± 8·7 during the first and second observation in the laboratory.	The I/O ratio calculated for the entire campaign was 0·84.	-	Tofful *et al.*, 2021
3.	PM_{10}, $PM_{2·5}$, PM_1, NO_2, CO_2	Two urban hospitals and one suburban hospital **(Dhaka, Bangladesh)**	October to November 2019 and December 2019 to	PM sampler: (Model: WP6930S, VSON Technology	Post monsoon and winter	PM_1, $PM_{2·5}$ and PM_{10} were 104·1 ± 67·6, 137·4 ± 89·2 and 159·0 ±103·3 respectively in (I) and 118·9 ± 74·0, 157·2 ±	High I/O ratios were observed for PM_1, $PM_{2·5}$, and PM10 ranging from	PM_1, $PM_{2·5}$, and PM_{10} were four times higher in winter than	Zaman *et al.*, 2021

	and TVOC		January 2020	Co., Ltd, Guangdong, China).		97·2 and 181·9 ± 112·8 respectively in (O).	0·72 to 1·15 in the post monsoon season and 0·88 to 0·92 in the winter season.	post-monsoon in indoor.	
4.	PM_{10} with its chemical composition, trace gases, carbonyl compounds and VOCs	University cafetaria in **(León, Spain)**	27th November to 1st December 2017	PM_{10} sampler: TCR TECORA (model 2·004·01)	-	**PM_{10}** **(I)** Occupancy: 35·6 ± 5·6 (I) Non-occupancy: 12·4 ± 3·4 **(O):** 23·3 ± 10 **Formaldehyde (I):** 8·8; (O): 1·3 and **Acetaldehyde (I):** 17·8	Expect for Ca^{2+} and K^{+}, the I/O ratios for all water-soluble ions were less than 1. The indoor levels of VOCs were higher than those observed outdoors.	-	Alves *et al.*, 2020
5.	PM_{10}, $PM_{2·5}$	Residential homes **(Oporto, Portugal)**	Between May 2018 and February 2019	DustTraks DRX Aerosol Monitors (Model 8533, TSI Inc., MN, USA)	-	Higher PM_{10} concentrations when measured in kitchens in comparison with living rooms 259 ± 118 and 146 ± 28 respectively. $PM_{2·5}$ in living rooms and bedrooms were 46 and 36, respectively.	In the absence of significant indoor sources, I/O < 1 (influence of outdoor sources), whereas if I/O > 1 (indoor values are most likely caused by indoor emission sources)	-	Madureira *et al.*, 2020

6.	$PM_{2·5}$ with chemical characterization	Two urban sites, a peri-urban and a rural site in **(Rome)** Two sites at a coastal location **(Gela, Sicily)**	January 2012 to March 2014	SILENT Sequential Air Sampler, FAI Instruments, Fonte Nuova, Rome for both indoors and outdoor	Summer and Winter	Urban and coastal sites during winter, resulted in very similar concentrations 21 and 24 (urban site), 17 and 15 (coast site) respectively.	I/O is always above 0·8 during summer as compared to winters. An exception is shown by the two winter-coastal sites which show I/O values for secondary species of about 0·9.	**Summer:** High PM at two Coast areas: 26 and 34 compared to urban site: 13 **Winter:** High in inlands: 26-34 compared to coast: 16	Tofful *et al.*, 2020
7.	PM_{10} and $PM_{2·5}$	Residential homes **(Krakow)**	March 2013 and September 2015	Laser photometer SidePak AM510 personal aerosol monitors, USA	Autumn (A), winter (W), summer (S) and spring (Sp)	Daily average level of PM_{10} (O) and (I) were 47 and 24 respectively Daily average level of $PM_{2·5}$ (O) and (I) were 17 and 27 respectively	Not available	**PM_{10} (I):** (A): 29; (W): 30; (S): 14; (Sp): 22 **PM_{10} (O):** (A): 64; (W): 76; (S): 24; (Sp): 43 **$PM_{2·5}$ (I):** (A): 22; (W): 21; (S): 11; (Sp): 17 **$PM_{2·5}$ (O):** (A): 38; (W): 43; (S): 14; (Sp): 30	Ścibor *et al.*, 2019

8.	$PM_{2·5}$ and its chemical constituents	Indoor (School classroom) and outdoor (corridor) **(Kuala Lumpur, Maylasia)**	19th September 2017 to 16th February 2018.	Optical $PM_{2·5}$ sensor	-	**$PM_{2·5}$ (24 hr average)** (I): 11·2 ± 0·45; (O): 11·4 ± 0.44 **$PM_{2·5}$ (8 hr average)** ranges between (I): 3·2 and 28; (O): 3·2 and 19 Highest ion concentration in (I) is of Ca^{2+} (38·5 ± 35·0 μg g^{-1}) whereas in (O) it is SO_4^{2-} (30·6 ± 9·37 μg g^{-1})	The maximum I/O value of 2·5 was determined during a period when the classroom was unoccupied,	-	Othman *et al.*, 2019
9.	$PM_{2·5}$, PM_{10} and gaseous pollutants (SO_2 and NO_2)	Indoor (School classroom) and outdoor (balcony) **(Beijing, China)**	Heating period (6th to 13th January 2015) Non-heating period (15th to 22th September 2015).	Parallel aerosol samplers (MP S300, Sibata Scientific Technology LTD, Saitama, Japan)	Heating and non-heating period	**Heating Period (I) and (O) respectively** **PM_{10}:** 113 ± 47·0 and 136 ± 51·2; $PM_{2·5}$: 81·1 ± 35·8 and 89·5 ± 36·7; SO_2: 57·1 ± 27·7 and 70.2 ± 31.4; NO_2: 126 ± 29·5 and 142 ± 40·7; **Non-heating Period (I) and (O) respectively** PM_{10}: 108 ± 51·3and 144 ± 30·8 $PM_{2·5}$: 71·4 ± 34·0 and 80·2 ± 23·4 SO_2: Nil and 8·7 ± 4·6 NO_2: 81·2 ± 20·7 and 123 ± 19·8	Not available	Indoor ($PM_{2·5}$, PM_{10}) and (SO_2, NO_2 and O_3) showed lower levels than outdoor during both periods. During both periods, higher abundance of SO_4^{2-}, NO_3^- and NH_4^+ than other ions in indoor and outdoor $PM_{2·5}$	Zhang *et al.*, 2019

10.	$PM_{2·5}$ (its chemical constituents), VOCs and trace gasses (NO_2 and O_3)	Municipality aquatic centre **(Kozani, Greece)**	6th to 15th of June 2016	Low Volume Air sampling Systems (Derenda LVS3·1/PM S3.1-15 and Teccora	-	**$PM_{2·5}$ (I):** 13·96; **(O):** 6·78 NO_2 and O_3 were 113·07 ± 50·96 and 59·90 ± 11.14 in (I) respectively and 63·31 ± 14·33 and 81·96 ± 5·55 respectively (O).	The I/O ratio for $PM_{2·5}$ was above 1·5, indicating presence of indoor sources.	-	Tolis *et al.*, 2018
11.	$PM_{2·5}$, PM_{10} and their chemical constituents	Office building **(Doha, Qatar)**	22nd April to 21st June 2015.	High volume samplers (LVS16 by WB Engineering GmbH)	-	Average concentration of $PM_{2·5}$ and PM_{10} were 15·5, 21·2 respectively (I) and 172, 267 respectively (O)	I/O ratio was found to be significantly lower than unity (0·12 ± 0·07 for $PM_{2·5}$ and 0·09 ± 0·04 for PM_{10})	-	Saraga *et al.*, 2017

Table 2: Concentration and composition of PM, trace gases and metals studied simultaneously indoors and outdoors in India.

S. No.	EXPOSURE DETAILS					RESULTS			REFERENCE
	I/O pollutant details	**Site descriptions**	**Period of study**	**Samplers used**	**Seasonal comparison**	**Average Indoor (I) and outdoor (O) concentrations (µg/m³)**	**I/O Output**	**Seasonal Output**	
1.	PM_{10}, $PM_{2·5}$ CO, CO_2, NO_2, SO_2, NH_3, H_2S,	Rural and urban residential homes **(Lucknow, UP)**	November 2014 to October 2015	APM 550, Envirotech	Summer (S), winter (W) and rainy (R)	**$PM_{2·5}$ Rural (I):** 51 (S), 143 (R), 210 (W) and **(O):** 47·5 (S), 22 (R), 44·25 (W)**; $PM_{2·5}$ Urban (I):** 160 (S), 84 (R), 185 (W) and **(O):** 106 (S), 65 (R), 90 (W) **PM_{10} Rural (I):** 87 (S), 264 (R), 315 (W) and	The I/O ratio of $PM_{2·5}$ in (W) and PM_{10} in (R) were 2·0 and 1·5 respectively, whereas in rural the ratio exceeded 4·0	Pollutants were in higher concentration in winters followed by summer and rainy season. H_2S concentration	Lawrence *et al.*, 2019

						(O): 103·25 (S), 112·75 (R), 63·5 (W)**; PM_{10} Urban (I):** 215 (S), 145 (R), 280 (W) **and (O):** 237 (S), 93 (R), 211 (W)	I/O ratio for NO_2 in (S), CO_2 in (W) and NH_3 in (W) were 1·7, 1·3 and 13·9 respectively.	were very low in each season.	
2.	PM (and its associated metal concentration)	Sub Urban and urban traffic sites **(Mumbai, Maharashtra)**	August 2016 to January 2017.	Leland Legacy Sample pump (SKC Cat. No. 100-3002, USA)	-	At urban and sub-urban sites respectively **$PM_{1·0-2·5}$ (I):** 49·19 ± 1·23 and 50·512 ± 7·38 **(O):** 56·08 ± 2·99 and 58·19 ± 7·56 **$PM_{0·5-1·0}$ (I):** 38.06 ± 0·94 and 38·32 ± 4·54 **(O):** 49·14 ± 4·61 and 45·47 ± 2·62 **$PM_{0·25-0·5}$ (I):** 33·38 ± 1·42 and 36·72 ± 4·91 **(O):** 40·83 ± 3·41 and 38·10 ± 4·68	The range of the I/O ratio for $PM_{1–2·5}$, $PM_{0·50–1·0}$, $PM_{0·25–0·50}$ was 0·53 to 2·07 and for metal concentration it was 0·09 to 1·18 for urban and suburban site.	-	Masih *et al.*, 2019
3.	$PM_{2·5}$, CO_2 and VOCs	School Classroom **(Himachal Pradesh)**	May to June, 2018	Forbix Semicon air quality monitor and dust meter	-	**$PM_{2·5}$ (I):** 191 and **(O):** 237 **CO_2 (I):** 435-590 ppm and **(O):** 413-557 ppm	Not available	-	Shree *et al.*, 2019

Table 3: Concentration and composition of PM, trace gases, inorganic and organic compounds studied outdoors only.

S. No.	EXPOSURE DETAILS					RESULTS			REFERENCE
	Outdoor pollutant details	**Site descriptions**	**Period of study**	**Samplers used**	**Seasonal comparison**	**Average outdoor concentrations ($\mu g/m^3$)**	**Output**	**Seasonal Output**	
1.	$PM_{2·5}$ and its chemical constituents, OC, EC	University of rooftop (urban) **(Hanoi, Vietnam)**	8th to 30th July 2020.	Low-volume air sampler (METONE, E-FRM-200, USA)	-	$PM_{2·5}$ concentrations measured for the whole sampling period was 40·205 OC: 11·853± 6·425; EC: 1·342± 0·774	Daily $PM_{2·5}$ concentrations exceeded the national standard for ambient air quality	-	Luong *et al.*, 2021
2.	$PM_{2·5}$, SO_2, NO_2, O_3, and trace elements in $PM_{2·5}$	Three urban sites **(Hanoi, Vietnam)**	February 17th, 2020 to March 23rd, 2020 (before lockdown) April 1st, 2020 to April 22nd, 2021 (during partial lockdown)	High-volume air sampler (Shibata HV 500R, Japan)	-	**Before Lockdown** $PM_{2·5}$: 52·9 NO_2: 11·6 SO_2: 4·5 O_3: 12·2 **During partial Lockdown** $PM_{2·5}$: 43·4 NO_2: 5·2 SO_2: 5·1 O_3: 17·1	During the partial lockdown, NO_2, $PM_{2·5}$, O_3, and SO_2 decreased by 75·8, 55·9, 21·4, and 60·7% respectively.	-	Nguyen *et al.*, 2021
3.	$PM_{2·5}$, WSIC, Organic Carbon (OC), Elemental Carbon (EC) and Polyaromatic hydrocarbons (PAH)	University rooftop, urban site **(Bangkok, Thailand)**	August 2017 to March 2018	MiniVol portable air sampler	-	**$PM_{2·5}$:** 77·0±21·2 **TC:** 10·65±5·39 **OC:** 8·03±4·02 **EC:** 2·62±1·49	Mean $PM_{2·5}$ concentrations were 3 times higher than the annual average concentrations specified in the Thai National Ambient standard.	-	ChooChuay *et al.*, 2020

Table 4: Concentration and composition of PM, trace gases, inorganic and organic compounds studied indoors only.

S. No.	EXPOSURE DETAILS					RESULTS			REFERENCE
	Indoor pollutant details	**Site descriptions**	**Period of study**	**Samplers used**	**Seasonal comparison**	**Average indoor concentrations (µg/m^3)**	**Output**	**Seasonal Output**	
1.	Trace gases (NH_3, NO_2 and SO_2) and their respective particulate ions	Residential homes of two sites. (DH- Dwarika households and MH- Mayapuri households) **(New Delhi, India)**	July 2017 to June 2018	Wet Chemical Impinger Method	Summer (S), monsoon (M) and winter (W)	DH **NO_2** (S): 7·93 ± 1·74, (M): 10·4 ± 3·47 and (W): 12·4 ± 3·56; **SO_2** (S): 10·5 ± 3·67, (M): 8·07 ± 4·30 and (W): 12·5 ± 4·01; **NH_3** (S): 72 ± 30·5, (M): 165 ± 54·6 and (W): 89·2 ± 33·3 MH **NO_2** (S): 7·05 ± 3·66, (M): 9·57 ± 3·91 and (W): 9·58 ± 2·81; **SO_2** (S): 10·9 ± 5·29, (M): 10·6 ± 5·23 and (W): 22·9 ± 6·29; **NH_3** (S): 35·8 ± 24·7, (M): 114 ± 55·3 and (W): 35·7 ± 18·9	Relative abundance of trace gases followed the order NH_3 > SO_2> NO_2 at both the sites.	NH_3 concentrations were highest during monsoon due to high relative humidity and temperature whereas SO_2 and NO_2 were highest during winter.	Katoch and Kulshreshtha, 2021
2.	$PM_{2·5}$, trace metals and BTEX	University building **(Bangi, Selangor)**	January to February 2019	MiniVol Portable Air Sampler (Airmetrics Mini Vol, Eugene, OR, USA	-	Average mass concentration of $PM_{2·5}$ was 80·2 ± 31·1 (for the upper floor) and 96·4 ± 27·0 (for the lower floor)	$PM_{2·5}$ results for both Floors were higher than the standards provided by the EPA.	-	Amira 'Ainaa' Idris *et al.*,2020

OBJECTIVES

The indoor environment is overlooked in the environmental health discourse, despite the considerable health risks that can arise. It is important to improve our understanding on how outdoor air influences the indoor air quality under different environmental conditions to develop efficient control strategies to reduce its impact on human exposure and thus human health risk. Therefore, studies must be conducted to enrich our present state of knowledge on the variability of particulate matter, chemical composition, its transport pattern, indoor–outdoor relationships, and meteorological conditions, at places where most of the people reside and work (residential places and school or university sites).

To obtain a complete overview, simultaneous indoor and outdoor measurements are deeply desired at the University Campus and residential site. Recognizing the importance of such studies, it is proposed to carry out the simultaneous measurements of air pollutants – particulate matter, its inorganic and organic chemical constituents, both indoors and outdoors at two sites (a) University Campus; (b) Residential Site.

Thus, the present study has been planned with the following objectives:

1. To measure particulates (outdoors as well as indoors), few representative samples of particulate matter ($PM_{2\cdot5}$ and PM_1), water-soluble anions (F^-, Cl^-, NO_3^-, SO_4^{2-}) as well as cations (NH_4^+, Na^+, K^+, $Ca^{2+,}$ Mg^{2+}) simultaneously both indoors and outdoors for the assessment of indoor-outdoor relationships.
2. To estimate metals (As, Pb, Cu, Zn, Fe, Al, Ni and Cd) and organic constituents− carboxylic acids and representative VOCs (HCHO and BTEX) for the investigation of its impact on human health, indoors and outdoors.
3. To evaluate the variation in aerosol constituents with meteorological conditions and transport pathways.
4. Source apportionment to differentiate indoor and outdoor sources using various statistical tools (correlation, regression, Principal Component Analysis) and models (E-AIM, Positive Matrix Factorization, HYSPLIT).

METHODOLOGY

SITE DESCRIPTION AND LOCATION

Agra is located in the north central (27°10' N, 78°05' E) part of India which is about 200 km southeast of Delhi and lies in the middle of the Indo-Gangetic Plain. Climatically, Agra is hot and dry during the summer and cool in the winter. The annual rainfall is about 650 mm with 90% being received during monsoon season (July–September). Winter is associated with calm periods while during the summer and monsoon strong surface winds are observed. In summer, temperature ranges from 25°C to 45°C, while in the winter it ranges from 3°C to 10°C. Relative humidity is highly variable from 25–99%. Apart from the local sources Mathura refinery and Firozabad glass industries are both situated at a distance of 40 km from Agra. National Highway lies about 2 km from the sampling site. Although there are no industries in the immediate vicinity of the sampling site, during the monsoon, site becomes downwind with respect to the city's pollution sources.

The differences in ambient pollutant exposure between these two sites may have different impacts on building dwellers. Other factors may influence pollutant impact, such as building occupancy and activity, which will be monitored in line with indoor and outdoor pollutant monitoring. The sampling will be carried out both outdoors and indoors at two sites:

a) **University Campus -** Dayalbagh Educational Institute (DEI), Dayalbagh – DEI is surrounded by a small residential community and agricultural fields.

b) **Residential site -** Behind Kendriya Hindi Sansthan, Mau Road – is a typical urban residential area surrounded by residential houses and multi-storied flats. It is mainly influenced by domestic activities. Most of the families use LPG for cooking in this area. People chiefly use four-wheelers or two-wheelers for transport.

SAMPLING AND ANALYSIS

Both locations will be equipped with similar sampling conditions for the collection of pollutant species simultaneously (outdoors as well as indoors).

SAMPLING

Envirotech APM 821: The sampling of particulate matter and other gaseous/organic pollutants, indoors as well as outdoors, will be done using portable, handy, low volume air sampler Envirotech APM 821. Its system uses a small battery-operated pump to draw air. It has two series of impingers to monitor gas pollutants. There is an additional provision to determine suspended particulates in the same sampler by using the open sampling head which requires 25 mm diameter filters.

Envirotech APM 550 (for $PM_{2\cdot5}$) and Envirotech APM 577 (for PM_1): To obtain overall view of outdoor environment, representative samples of $PM_{2\cdot5}$ and PM_1 will also be collected. The collection of particulate matter and other chemical constituents will be done using high volume air samplers - Envirotech APM 550 (for $PM_{2\cdot5}$) and Envirotech APM 577 (for PM_1).

ANALYSIS

After extraction the particulate and gaseous pollutants will be subjected to analysis as mentioned:

1. **Inorganic constituent of particulate matter:** The analysis of inorganic ions (cations and anions) will be done by Dionex ICS-1100 (ion exchange chromatograph)**.** A portion of filter paper will be extracted in ultra-pure water (≥ 18·2 MΩ resistivity). The water-soluble ions (Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}) will be analyzed by Dionex IonPac CS12A column and a cation self-regenerating suppressor CSRS (4 mm) using methane sulfonic acid as eluent at a concentration of 20 mM with a flow rate of 1·0 ml min^{-1}. Similarly, for anions (F^-, Cl^-, NO_3^-, SO_4^{2-} and organic acids) IonPac AS11 column and anion self-regenerating suppressor ASRS-ULTRA II (4 mm) using 20 mM NaOH as eluent with a flow rate of 1 ml min^{-1}. Before the analysis, calibration plots will be made for anions and cations, using single- and multi-component standard solutions for Ion Chromatography.
2. **Organic compounds and VOCs:** Representative samples will be collected at both sites by active grab sampling method for the analysis of VOCs. A battery-operated portable sampling pump (SKC 224-XR) will be used to draw air at the rate of 0·1 ml min^{-1} for 1 hour through SKC adsorption cartridge containing activated charcoal (60–80 mesh). The sampling pump will be calibrated by an electronic digital flow calibrator. Six samples per day will be collected to diurnal studies. The sample tubes will be placed in polythene bags that seal tightly and kept in a box in a deep freezer

until analysis. Extraction of samples will be done in CS_2. Analysis will be done by Agilent 5977B Gas Chromatography Mass Selective Detector/Flame Ionization Detector (GC-MSD/FID, Agilent Technologies, USA). Analyses will be performed by injecting 1 μL of extract in injector (250 °C) in a split mode, (split ratio will be 27:1 and split flow will be 32·4 mL/min). Sample will be first separated by a DB-17MS capillary column (30 m length × 0·25 mm internal diameter × 1·25 μm film, Agilent Technologies, USA), with helium as the carrier gas at a constant rate of 5.0 mL/min, and to a HP-5MS column (30 m length ×0·25 mm internal diameter × 1·25 μm film, Agilent Technologies, USA) output to flame ionization detector (FID) detection. The GC oven temperature will be programmed to be initially at 50 °C, held for 3 min; then increased to 140 °C at 10 °C/min, and then to 240 °C at 20 °C/min with a final hold time of 19 min. The MSD will be operated in selected scan monitoring mode.

3. **Metals:** The analysis of metals will be done using Inductively coupled Plasma – Optical Emission Spectroscopy (ICP-OES 5110 system, Agilent Technologies, USA). A portion of the filter paper will be cut and extracted with 6-8 ml of reagent grade HNO_3 over a hot plate at 40-60°C until a small portion of acid is left. The sample will then be diluted up to 50 mL with distilled de-ionized water and stored in polytetrafluoroethylene (PTFE) bottles until they are subjected to analysis (Agarwal *et al.*, 2017).
4. **HCHO:** The analysis of HCHO will be done in the following manner using UV-Vis Spectrophotometer (Perkin Elmer, Lambda 365).

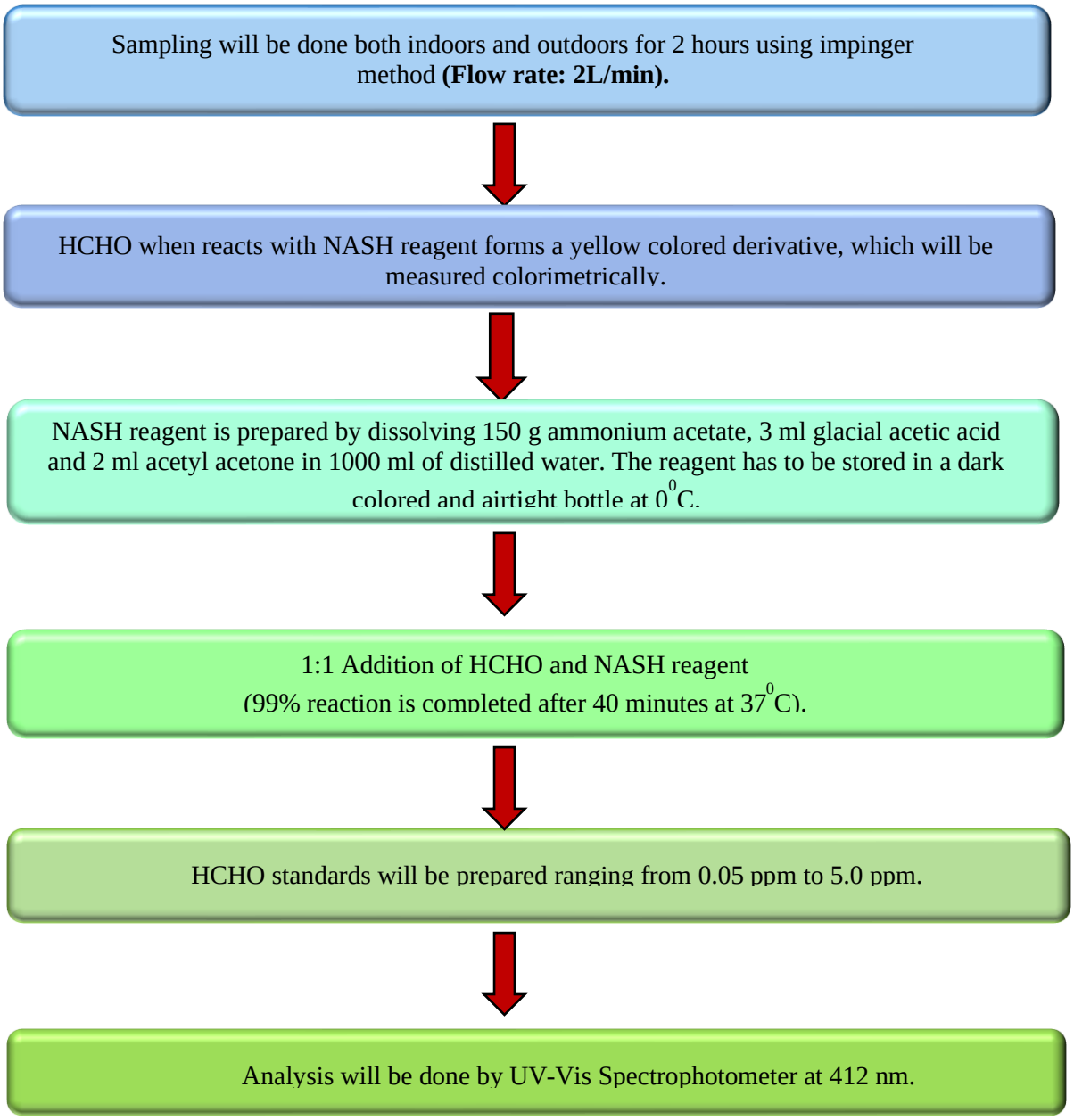
Sampling will be done both indoors and outdoors for 2 hours using impinger method (Flow rate: 2L/min).
HCHO when reacts with NASH reagent forms a yellow colored derivative, which will be measured colorimetrically.
NASH reagent is prepared by dissolving 150 g ammonium acetate, 3 ml glacial acetic acid and 2 ml acetyl acetone in 1000 ml of distilled water. The reagent has to be stored in a dark colored and airtight bottle at 0 0C.
1:1 Addition of HCHO and NASH reagent
(99% reaction is completed after 40 minutes at 37 0C).
HCHO standards will be prepared ranging from 0.05 ppm to 5.0 ppm.
Analysis will be done by UV-Vis Spectrophotometer at 412 nm.

Figure 2: Schematic procedure for the analysis of HCHO.

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